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EXPERIMENTAL ANALYSIS OF A SOLAR FLAT PLATE COLLECTOR FOR ENHANCEMENT IN THERMAL PERFORMANCE USING SOLAR TURBULENCE GENERATORS

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ABSTRACT

Solar air heaters are now-a-days used in space heating as well as a process heating in domestic applications. Since it is a renewable energy conversion device, enhancement of such devices assumes greater significance due to its lower efficiency. In this analysis, an attempt is made to improve the effectiveness of the solar collector by incorporating turbulence generating devices on the side walls of the air heater duct, which are energized by solar photo voltaic cells. The turbulence generators introduce swirl motion around them which enhances mixing of the hot and cold side of the fluid, resulting in enhanced heat transfer. It is noted from the study that with an increase in mass flow rate inside the duct, air heater with turbulence generating devices shows a remarkable improvement in the heat transfer with significant improvement in temperature rise across the duct compared to that of the smooth duct configuration. These results corroborate well with the corresponding drop in absorber plate temperature. However, with an increase in mass flow rate corresponding to the lower rotational speed of turbulence generators, the air heater with turbulence generators show a decrement in the heat transfer capacity. This results in reduction of the heat transfer capability and leads to lower temperature rise.

***KEYWORDS:** Solar Air Heater, Turbulence Generators, Convective Heat Transfer & Photo Voltaic Cells*

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Original Article

1. INTRODUCTION

Heating of the air using solar energy is a technology used now-a-days for space and process heating applications. A host of researchers have shown that the convective heat transfer capability of solar collectors can be enhanced by causing turbulence in the fluid flow and various techniques are adopted to achieve the same.

Liu et al. [1], in their study of flat plate collectors indicated that providing extended surfaces on the absorber plate helps in reducing the temperature of the absorber plate. Their analysis indicated that the absorber plate temperature decreased significantly when pin fins on the absorber plate with various configurations were provided.

Persad et al. [2] developed analytical models for the prediction of the performance of a solar air heater with two-glass-covers. It was found that single pass configuration performed relatively lower than that of two pass configurations for the operating range of the collector.

Giovanni Tanda [3] indicated that rib-roughened channels of a solar air heater perform better in terms of thermal performance compared to that of smooth duct collector in the lower to medium range of Reynolds number.

Karwa etal. [4] conducted a thermal analysis of a solar air flat plate collector with downward – v discrete rib roughness on the air flow side of the absorber plate, which supplied heated air for space heating applications.

The authors presented performance plots for the purpose of utilization by a designer for calculating desired air flow rate at different ambient temperature and solar isolation values.

Vasudeva etal. [5] conducted a numerical study of a solar flat plate collector with square cross section turbulators in the form of arcs introduced on the absorber plate. Compared to that of V shaped and straight configurations of the turbulator, arc shaped turbulators provided a better thermal performance. Turbulators with backward arc arrangement provided a better convective heat transfer compared to that of forward arc arrangement of the turbulators.

Abhishek et al. [6], in their review article focused on the developments that have followed in various aspects of solar air heating systems. They presented several methods to enhance the thermal performance of air heaters such as; optimizing the dimensions of the air heater construction elements, use of extended surfaces with different shapes and dimensions, integrating photovoltaic elements with the heaters, etc, have been analyzed.

Kabeel et al. [7] experimentally analyzed the thermal performances of flat, finned, and v-corrugated plate solar air heaters. It was found that the thermal efficiency of the v-corrugated solar air heater was 8–14.5% and 6–10.5% higher than that of flat and finned plate heaters, respectively.

Satyender et al. [8] studied the thermal performance of a single-pass single-glass cover solar air heater consisting of semicircular absorber plate finned with rectangular longitudinal fins. Results revealed that the use of double-glass cover and recycle operation improved the thermal performance of solar air heaters.

As suggested by Abhishek et al. [6], integrating photovoltaic elements with the heaters help to add a new dimension to the air heating capability of the solar collector. Hence, in this study a solar air heater is devised to enhance the thermal efficiency by introducing solar powered turbulence generators. It is expected that the turbulence generators provide improved convective heat transfer mechanism inside the collector.

2. EXPERIMENTAL TEST RIG

2.1 Main Structure

The experimental test rig consists of two solar flat plate air heaters which are identical in shape and size. The first configuration is free of any turbulators to account for the general collector. The second collector is made up of a duct which has 6 turbulence generators as shown in figures 1 and 3.

Figure 1: The Experimental Test Rig consisting of Two Air Heaters Connected to a Common Blower.

The air heater consists of an absorber duct, an entrance duct and an exit duct which are assembled to form a single unit and free of air leakage. The absorber duct which is exposed to solar radiation consists of an absorber plate on the upper side and is made up of a 0.5 mm thick, 250 mm wide and 1.2 m long copper plate. The surface exposed to solar radiation is painted with black mat finish coating to absorb the maximum solar radiation. The height of the duct is 30 mm and the width of the duct is 250 mm. The remaining sides of the duct are made up of wooden structure to provide insulation to the heated air. The inside surface of the wooden structure is provided with a smooth surface to prevent the flow losses along the flow path. The entrance duct and the exit duct are made up of plywood material with an entrance length of 500 mm and an exit length of 250 mm. However, the exit duct has a converging section towards the exit and provision is made for further connections. The length of the entrance and exit duct is adopted as per ASHRAE standards.

2.2 Turbulator Fan

The turbulence generators are made up of 4 radial, 2 mm thick and 15 mm wide blades with a hub diameter of 6 mm and outer diameter of 25 mm as shown in fig 2. These turbulence generators are 6 in number and are mounted on the side walls of the absorber duct with a pitch of 0.3 m. They are driven by electric motors with provisions made for varying speeds. The turbulence generators are custom made components on the 3D printer and are of plastic material. The electric motors are powered by using photo voltaic cells which is exposed to solar radiation. These photo voltaic cells are placed on the collector entrance duct which is not exposed to solar radiation. The fans are driven in such a manner that all fans are rotated in the same clockwise direction when looking from the east end of the collector.

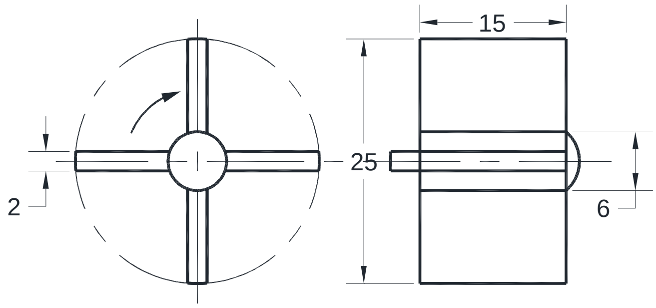

Figure 2: Schematic Diagram of the Turbulence Generator.

Figure 2 shows the schematic diagram of the turbulence generator used in the solar air heater. It has 4 radial blades and has a blade thickness of 2 mm with a face width of 15 mm mounted on a hub of 6 mm diameter. The clearance space between the side wall and the fan is 2.5 mm.

2.3 Accessories

The plain configuration and turbulator configurations of the solar air heaters are connected to a common blower so as to account for the same mass flow rates. The blower adopted in the study has provisions for 7 speeds of operation which gives 7 different mass flow rates as per the speed that is adopted. The solar radiation is recorded using a pyranometer and the sensor is mounted midway between the two collectors. The temperature profile of the absorber plates are noted using a thermal gun by recording the readings at 12 marked locations on the absorber plate. The temperature of the air inside the heater is recorded at 5 different locations along the flow path with the help of RTD type thermocouples. The reading of the same are continuously recorded using a data logger and the average temperatures are adopted for the analysis. The flow velocity of air is measured using an anemometer. Figure 1 shows the experimental test rig with the two air heaters connected to a common blower.

2.4 Electrical Connections

The turbulence generators are operated using solar photo voltaic cells and the power supply to all the six DC motors are regulated using a dimmer stat controller by connecting the motors in series connection and hence the turbulence generator speed is regulated in three steps. A custom made electric circuit is used to convert the solar cell generated current into the required 6V 3 amp current for the six DC motors in series.

3. EXPERIMENTATION

The experiments are conducted for 3 days between 11 p. m. and 1 p. m. when there was an average sun shine, so as to account for a generalized weather condition. The average heat flux measured during these 3 days was 560W/m^2 as recorded by the pyranometer. The temperature measured inside the duct was along with the mid span width of the air duct and at location which is 5 mm below the absorber plate. The ambient conditions were, still air and an average temperature of 35°C. The absorber plate temperatures were measured in every 5 minutes for 7 different mass flow rate of the blower.

The turbulence generator operating speeds are 1960 rpm, 2380 rpm and 2690 rpm. The mass flow rates achieved (in kg/s) by the blower in each of the ducts is shown in Table 1.

Table 1: Mass Flow Rate Corresponding to 7 Blower Speed Positions in each of the Ducts

Blower Position	Mass Flow Rate in kg/s
m1	0.01635,
m2	0.01828
m3	0.02020
m4	0.02212
m5	0.02405
m6	0.02597
m7	0.03078

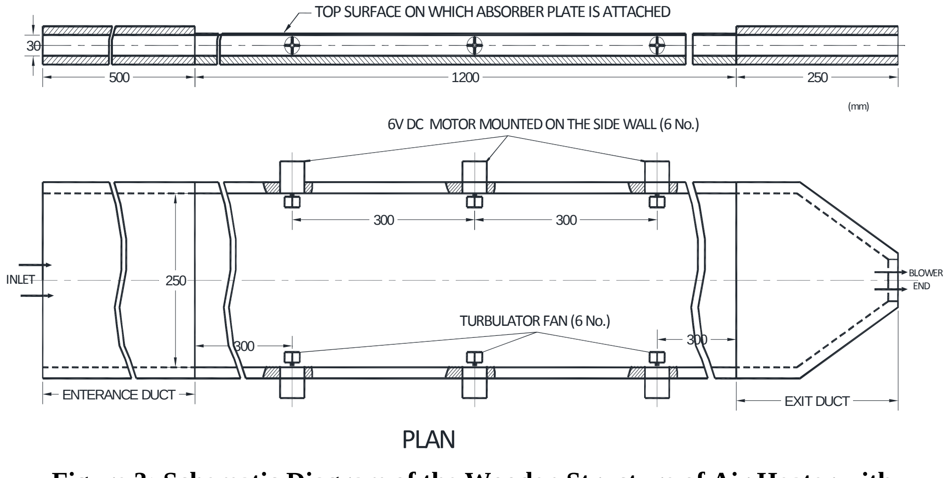

Figure 3: Schematic Diagram of the Wooden Structure of Air Heater with Turbulator Fans Inserted on the Side Walls of the Absorber Duct.

4. RESULTS AND DISCUSSIONS

The experimental data collected are presented in the form of bar charts and graphs as shown in Figures 4–16. Figures 4–6 show the relative percentage temperature drop for turbulator configuration and plain configuration corresponding to the three speeds of the turbulator and seven mass flow rates. The comparative percentage drop in absorber plate temperature of

turbulator with respect to plain configurations is calculated using equation 1 by determining the average absorber plate temperatures of Turbulator configuration (T_T) and plain configuration (T_p).

$$Percentage\,Temp.drop = \frac{T_T - T_P}{T_P} \times 100 \quad (1)$$

It can be observed from Figure 4 that the percentage temperature drop for turbulator configuration is positive at lower mass flow rates, indicating that the turbulator configuration absorbs more heat from the absorber plate compared to that of the plain configuration. However, the percentage temperature drop decreases and becomes negative with increase in mass flow rate, thus indicating that the plain configuration is more effective at higher mass flow rates when the turbulator speed is 1960 rpm.

It can be noted from figures 5 and 6 that the absorber plate temperature drop for turbulator configuration is greater compared to that of plain configuration for turbulator speed of 2380 rpm and 2690 rpm for all the seven mass flow rates. However, it is clear from these plots that the percentage drop is increasing with the increase in mass flow rate to certain extent and then decreasing. The largest percentage temperature drop is 4.71% for a mass flow rate of m5 corresponding to turbulator fan speed of 2380 rpm and 6.17% for mass flow rate of m4 corresponding to turbulator fan speed of 2690 rpm. The largest temperature drop is achieved for a low mass flow rate of m1 corresponding to turbulator fan speed of 1960 rpm which is 7.52%.

The reason for better heat transfer capability of the air heater with turbulence generators can be attributed to the fact that the turbulators introduced on the side walls increases turbulence near the absorber plate adjacent to the upper corners of the flow passage as the flow generally tends to be less disturbed at these regions. Also, the tip speed 'v' of the turbulence generators tend to be higher than the main stream flow velocity 'u' which enhances the flow regime in this region. Figure 7 shows the mechanism of flow around the turbulator fans for a better understanding of the flow behavior.

However, with an increase in mass flow rate corresponding to lower turbulator speeds, the air heater shows a decrement in the heat transfer due to the lower speeds, the turbulator produces lower tip velocity 'v' compared to the main stream flow velocity 'u', thereby acting as a drag on the through flow. This reduces the heat transfer capability and results in lower temperature rise of the fluid.

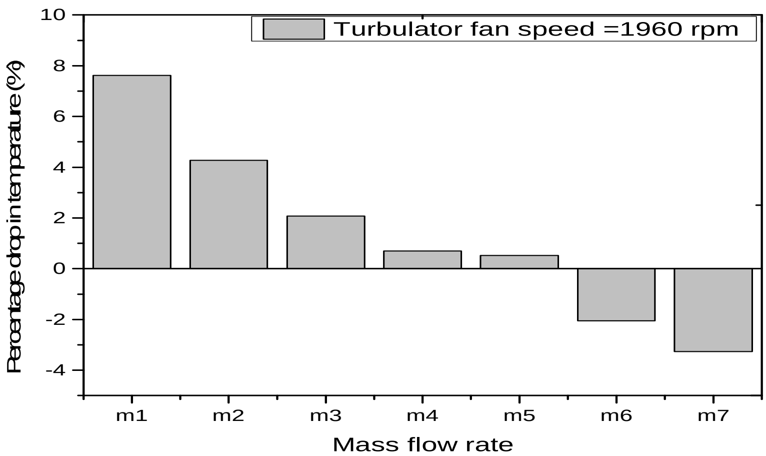

Figure 4: Absorber Plate Relative Percentage Temperature Drop for Turbulator Configuration in Comparison with that of the Plain Configuration Corresponding to Turbulence Generator Speed of 1960 rpm.

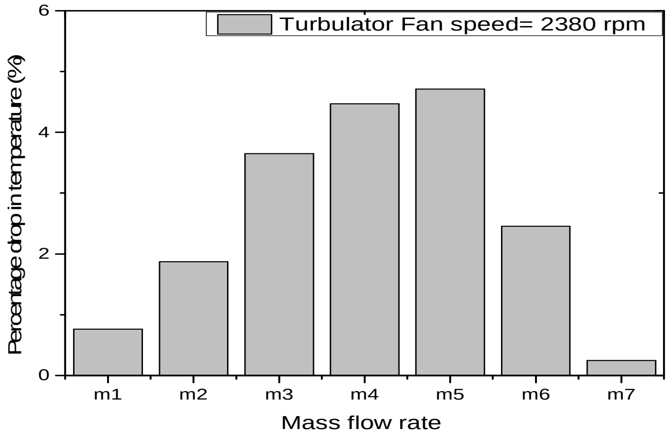

Figure 5: Absorber Plate Relative Percentage Temperature Drop for Turbulator Configuration in Comparison with that of the Plain Configuration Corresponding to the Turbulence Generator Speed of 2380 rpm.

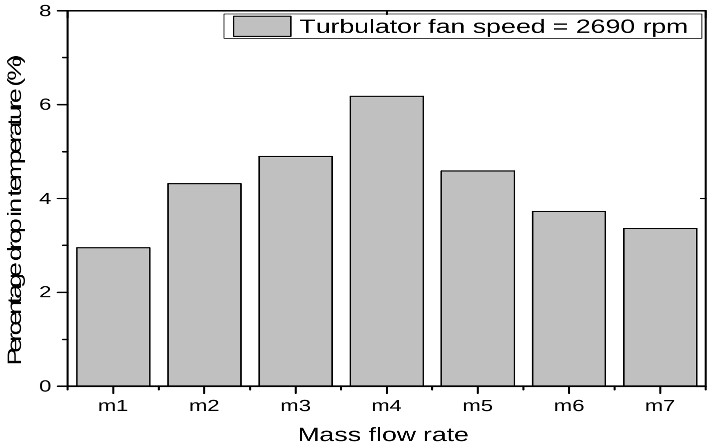

Figure 6: Absorber Plate Relative Percentage Temperature Drop for Turbulator Configuration in Comparison with that of the Plain Configuration Corresponding to Turbulence Generator Speed of 2690 Rpm.

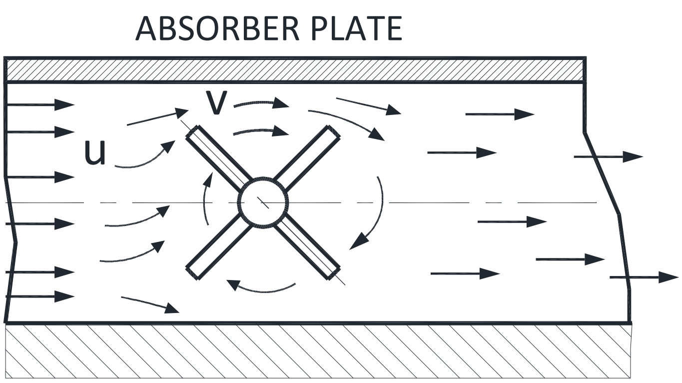

Figure 7: Flow Around the Turbulence Generator Inside the Absorber Duct.

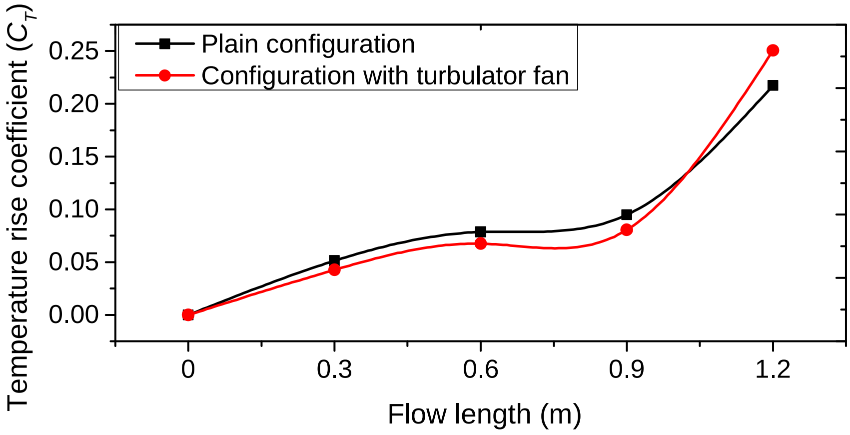

Figure 8: Absorber Air Temperature Coefficient along Flow Length at Mass Flow Rate m1 Corresponding to Turbulence Generator Speed of 1960.

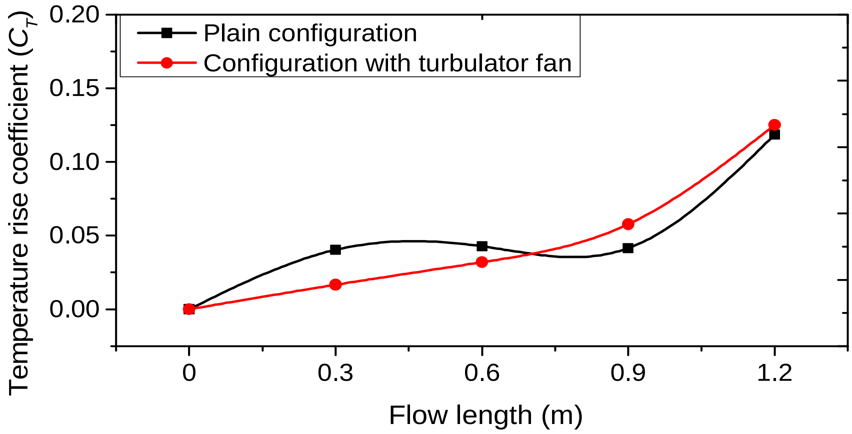

Figure 9: Absorber Air Temperature Coefficient along Flow Length at Mass Flow Rate m1 Corresponding to Turbulence Generator Speed of 2380.

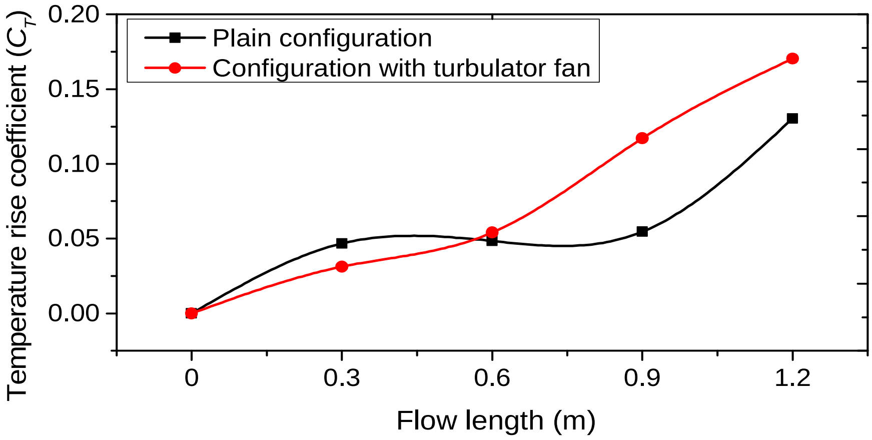

Figure 10: Absorber Air Temperature Coefficient along Flow Length at Mass Flow Rate m1 Corresponding to Turbulence Generator Speed of 2690.

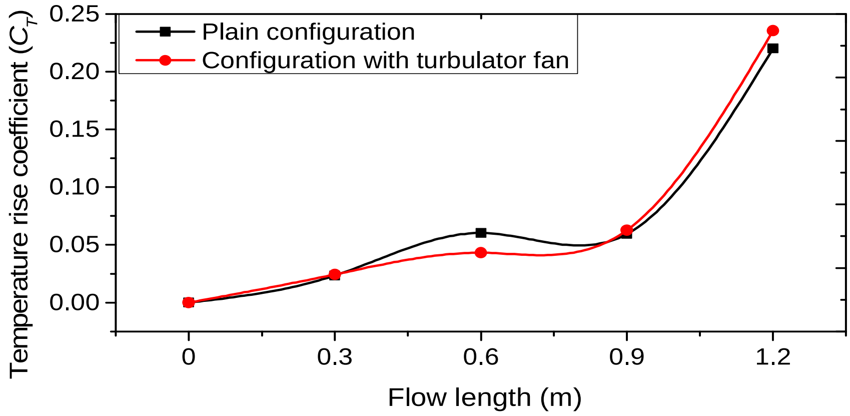

Figure 11: Absorber Air Temperature Coefficient along Flow Length at Mass Flow Rate m4 Corresponding to Turbulence Generator Speed of 1960.

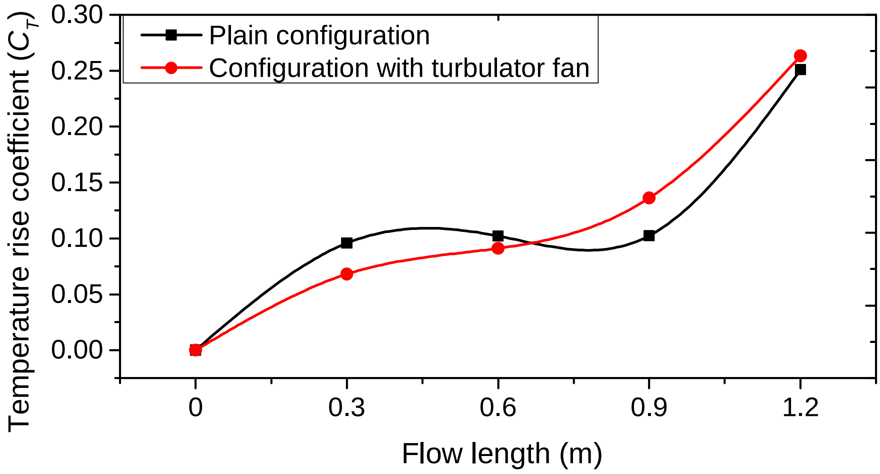

Figure 12: Absorber Air Temperature Coefficient along Flow Length at Mass Flow Rate m4 Corresponding to Turbulence Generator Speed of 2380.

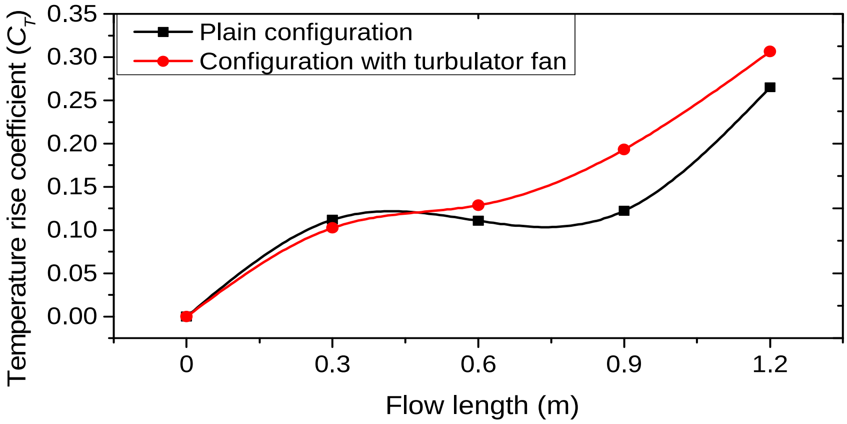

Figure 13: Absorber Air Temperature Coefficient along Flow Length at Mass Flow Rate m4 Corresponding to Turbulence Generator Speed of 2690.

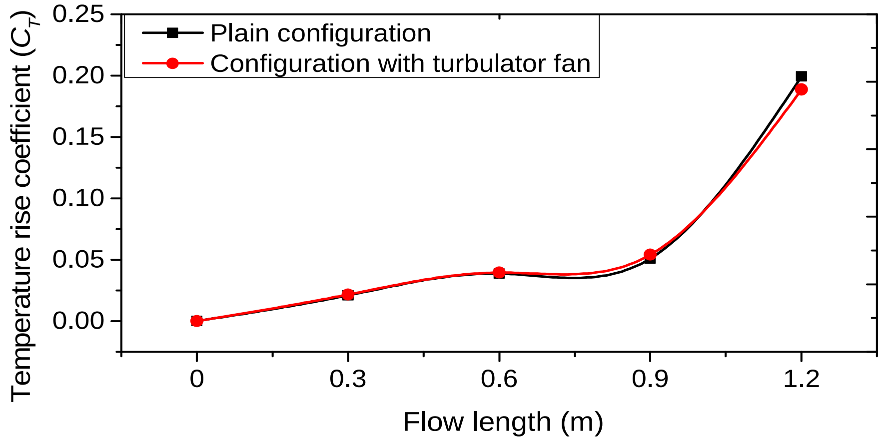

Figure 14: Absorber Air Temperature Coefficient along Flow Length at Mass Flow Rate m7 Corresponding to Turbulence Generator Speed of 1960.

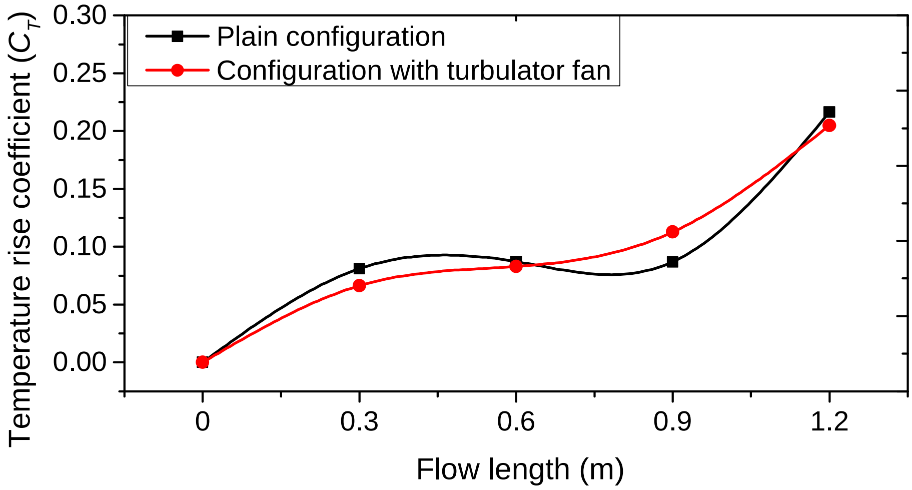

Figure 15: Absorber Air Temperature Coefficient along Flow Length at Mass Flow Rate m7 Corresponding to Turbulence Generator Speed of 2380.

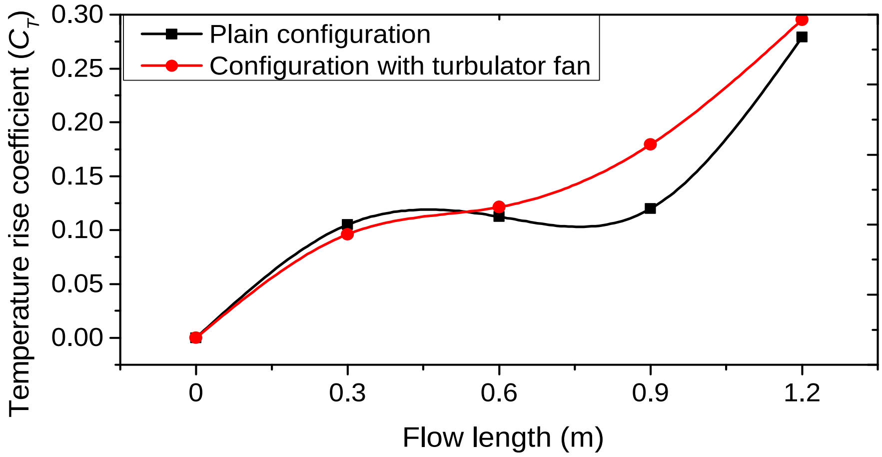

Figure 16: Absorber Air Temperature Coefficient along Flow Length at Mass Flow rate m7 Corresponding to Turbulence Generator Speed of 2690.

Figures 8–16 show the temperature plots of absorber air recorded along the flow path at a distance of 5 mm below the absorber plate at mid span width of the absorber duct. From these plots, it can be inferred that at lower speeds of turbulence generator corresponding to the mass flow rate m7, the temperature profile of plain duct configuration is better than that of the turbulator configuration as shown in Figure 14. This clearly corroborates with the absorber plate temperature plots shown in Figure 4 which shows that the plain duct configuration gives better heat transfer than that of turbulator configuration for mass flow rate m7. It can be also observed that the temperature profiles for all other turbulator speeds and mass flow rates are better than that of the plain configuration and thus indicating that turbulence generators enhances the heat transfer capability of the air heater.

5. CONCLUSIONS

The experimental study of solar air heater with turbulence generators attached to the side wall of the duct is carried out under fair weather conditions and the following conclusions are drawn.

- It is found from the experimental analysis that with an increase in mass flow rate of air in the duct, air heater with turbulence generators shows improvement in the heat transfer capacity with significant improvement in temperature rise across the duct compared to that of the air heater without the turbulence generators.
- With an increase in mass flow rate corresponding to lower turbulator speeds, the air heater with turbulence generators show a decrement in the heat transfer capacity.
- As the mass flow rate increases, for every turbulator speed, there is an optimal mass flow rate at which the heat transfer capability becomes maximum.

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REFERENCES

1. *Liu Ye-De, Diaz A, Suryanarayana N. V. (2009)" Heat Transfer Enhancement in Air-Heating Flat-Plate Solar Collectors". Journal of Solar Energy Engineering. The American Society of Mechanical Engineers. Volume 106(3). DOI 10.1115/1.3267608.*
2. *Persad P, Satcunanathan S. (2009)" The Thermal Performance of the Two-Pass, Two-Glass-Cover Solar Air Heater". Journal of Solar Energy Engineering. The American Society of Mechanical Engineers. Volume 105(3). DOI 10.1115/1.3266375.*
3. *Giovanni Tanda, "Performance of solar air heater ducts with different types of ribs on the absorber plate", Energy, Volume 36, Issue 11, November 2011, pp. 6651–6660.*
4. *KarwaRajendra, Srivastava V. (2012)" Thermal Performance of Solar Air Heater Having Absorber Plate with V-Down Discrete Rib Roughness for Space-Heating Applications". Journal of Renewable Energy, Hindawi Publishing Corporation. Volume 2013, pp 1–13.*
5. *Vasudeva K. Karanth, Manjunath M. S., N. Yagnesh Sharma, "Analysis of Solar Air Heater for [7] Enhancement of Thermal Performance Using Arc-Shaped Wire Turbulator". Fluid Engineering systems and Technologies, The American Society of Mechanical Engineers. Volume 7B, pp 1–8.*

6. *Hussein, M. M., & Abdullah, M. M. IV Characteristics of CDTE/PTNPS/AL2O3/PTNPS/SI Thin Film Solar Cell.*

7. *Abhishek Saxenaa, Varunb, A. A. El-Sebaiic, "A Thermodynamic Review of Solar Air Heaters", Renewable and Sustainable Energy Reviews, Volume 43, March 2015, pp. 863–890.*

8. *Kabeel A. E., A. Khalil, S. M. Shalaby and M. E. Zayed, "Investigation of the Thermal Performances of Flat, Finned, and v-Corrugated Plate Solar Air Heaters, J. Solar Energy Eng , ASME, 138(5), 051004 (Jul 19, 2016), PP 1–7.*

9. *Satyender Singh and Prashant Dhiman, "Thermal Performance Analysis of a Rectangular Longitudinal Finned Solar Air Heater with Semicircular Absorber Plate", J. Solar Energy Engg ASME, 138(1), 011006 (Dec 08, 2015).*

10. *Mahrous, A. (2013). Thermal performance of PCM based heat sinks. Int J Mech Eng, 2(4).*